Next European Dipole Insulation Development

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Next European Dipole

- R&D on advanced accelerator magnet technology for existing and future facilities
- A European effort to bring niobium-3 tin technology to maturity and to boost the competitiveness of European laboratories and industry
- Wind-and-react niobium-3 tin 15 Tesla 88mm bore dipole, to enable LHC upgrades

NED is a Research Activity within CARE

- WP1 Management and communication
- WP2 Thermal Studies and Quench Protection
- WP3 Conductor Development
- ***WP4 Insulation Development and Implementation***
- Working Group on Magnet Design and Optimization

NED Participating Labs and Institutes

- CCLRC, UK
- CEA, France
- CERN
- CIEMAT, Spain
- INFN-Milan, Italy
- INFN-Genova, Italy
- Twente University, Netherlands
- Wroclaw University, Poland

Niobium-tin insulation for wind-and-react: current method

- No organic material as it degrades during niobium-tin heat treatment
- Remove organic glass sizing by heating in air
- Some labs use palmitic acid as a lubricant "resizing"
- Wrap superconductor cable with glass fibre tape
  - Desized glass is fragile!
- Wind coil
- Heat treatment typically 660 C for some days argon/vacuum
- Vacuum impregnation with an epoxy
- Cure, demoulding

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What should NED Insulation work package focus on?

- Greatest challenge is *Industrialisation* of niobium-tin dipole production, eg for large number of s-LHC dipoles
- Cable wrapping is currently a problem – fragile desized glass fibre tape tears
- …so sizing is desirable but commonly-used sizings are not suitable for this application
- If the *sizing* issue can be overcome then mass-production will be easier

Scope of NED Insulation Development

- Write Insulation Specification
- Address the sizing issue
- Search for alternatives
- Use screening tests to economically assess alternatives
- Investigate effect of applied stress during vacuum impregnation
- Radiation studies

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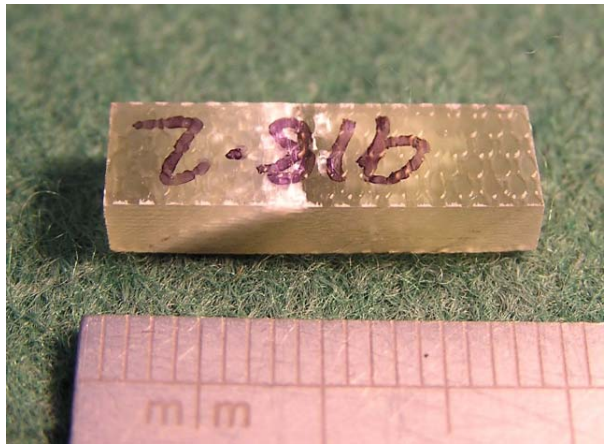
Screening test methods

- **4 Key tests chosen for screening of materials and process changes:**

1. Interlaminar fracture test used to determine Work of Fracture (ASTM5528)
   - Literature exists on low temperature application - Shindo
2. Short-beam-shear (ASTM D2344)
   - At 77K, tests fibre-to-matrix bond
3. Electrical breakdown strength BS7831
   - carbon residues from degraded organic material, e.g. sizing
4. Colour of composite
   - evidence of carbon residues

Interlaminar fracture

Short-beam shear



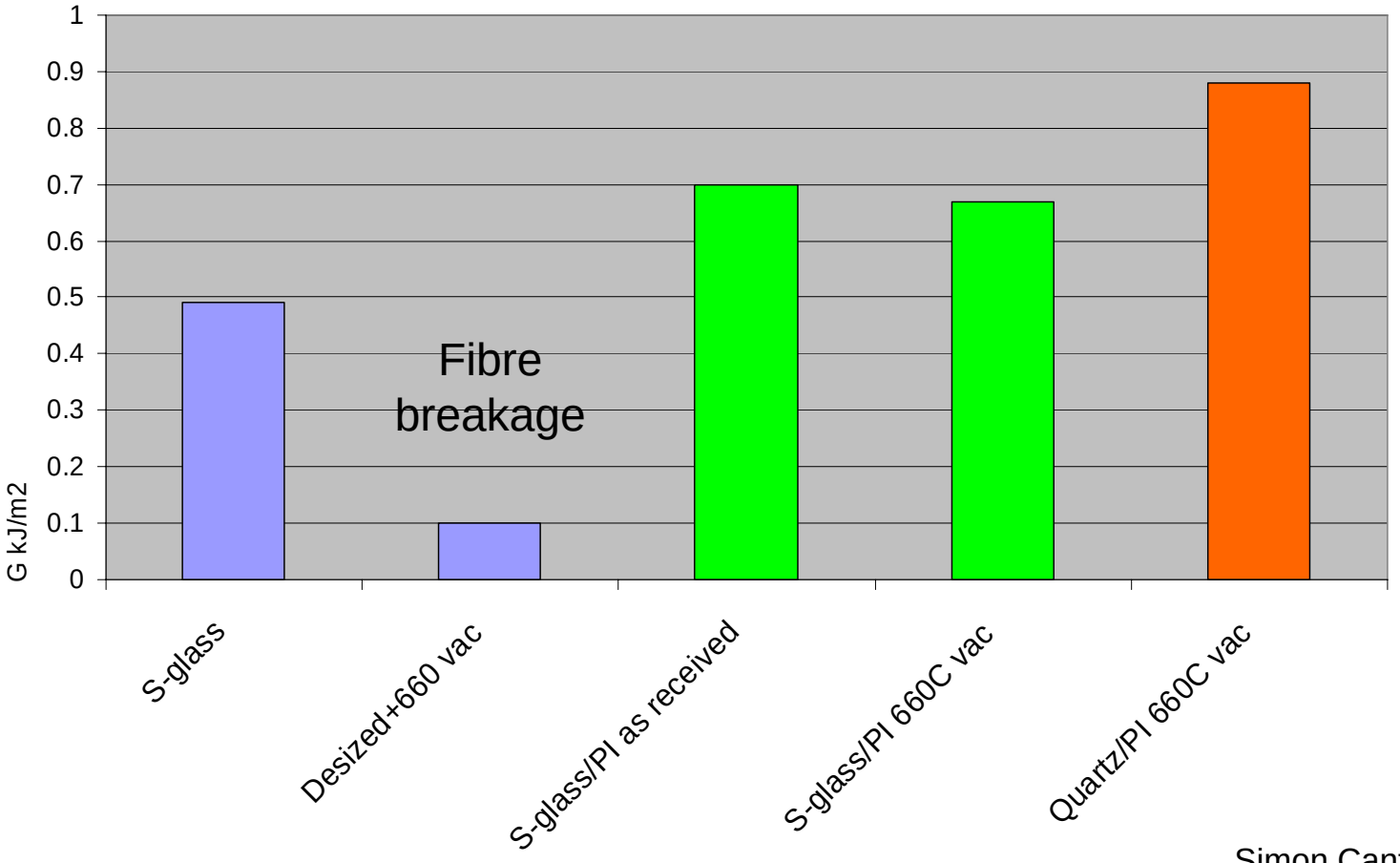
High temperature sizing

- Literature survey found a *polyimide sizing*
- Rated to 500°C in air
- Passes key NED specifications after 660 ° C in vacuum:
  1. Work of fracture better than S glass control
  2. Shear strength 100MPa
  3. Electrical breakdown strength >30kV/mm
  4. Composite is light in colour (indicating little or no carbon residue)

Work of fracture testing

•Heat-treated S-glass with Polyimide sizing gives higher work of fracture than control

•Epoxy resin = DGEBF/DETDA for all tests



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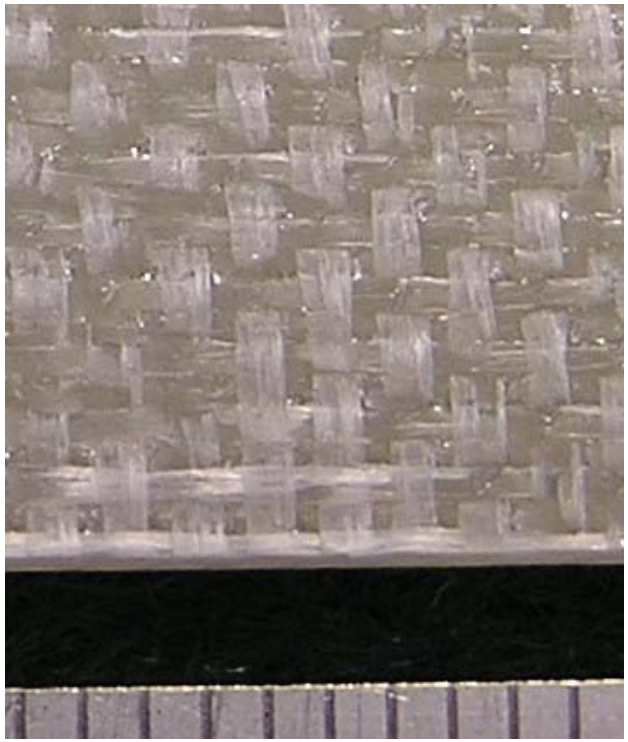
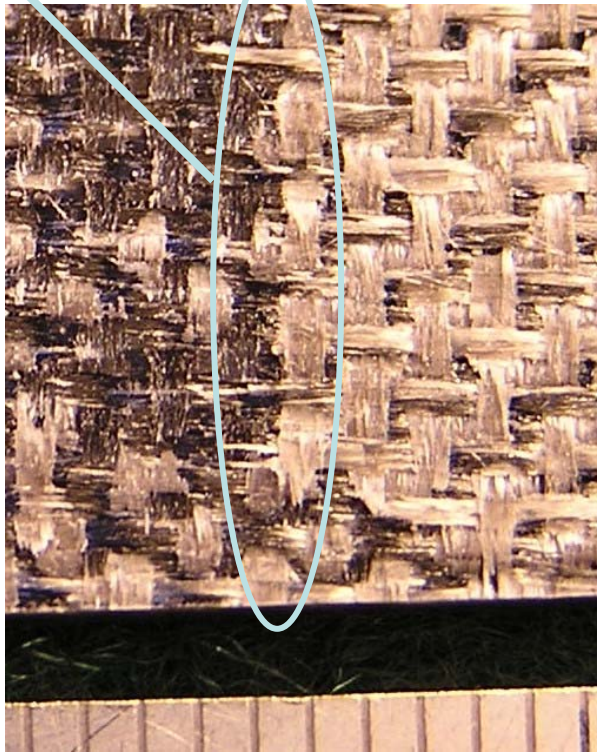
S Glass Fracture surfaces

No heat treatment- interlaminar failure



Broken fibres

Desized, heat treated Translaminar



Scale:mm

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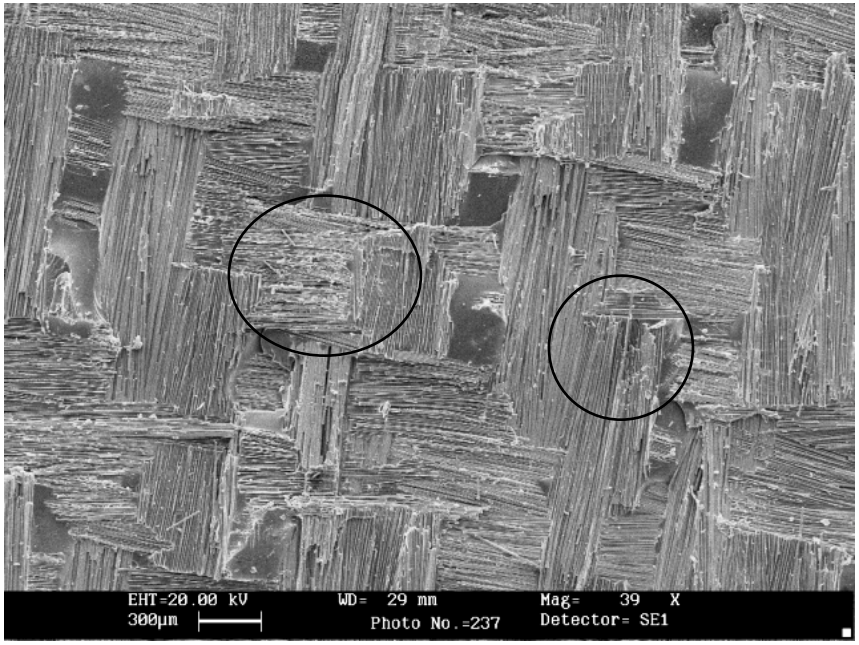
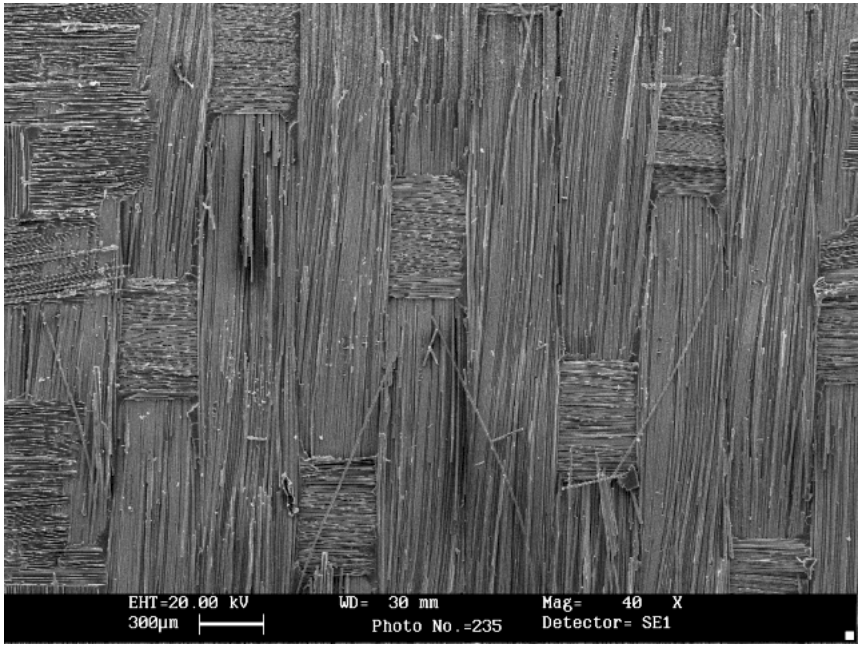
SEM - Fracture Surfaces



Desized/heat treated S-glass – note broken fibres



Polyimide sizing – fibres relatively intact

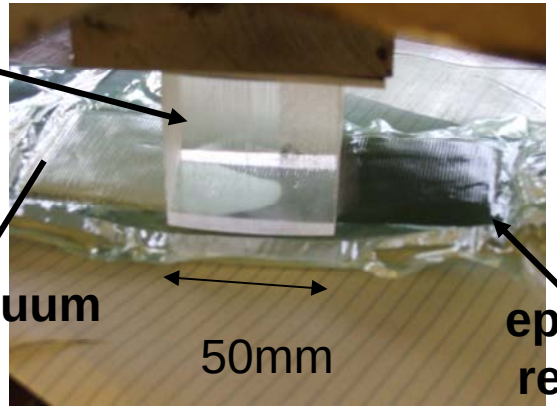
Vacuum impregnation under applied stress

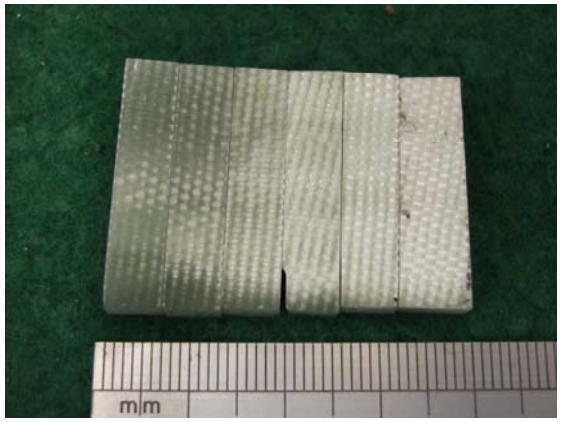
- Why? Because some stress is required to maintain accurate coil geometry
- Excessive stress is known to cause an opaque laminate
- We have vacuum impregnated glass cloth in a vacuum bag under stress, cured under stress, and measured short-beam-shear strength at 77K

Effect of applied stress on Short-Beam-Shear Strength

Force applied by an acrylic block, to enable viewing of impregnation

- High stresses (to date up to 10 MPa) did not stop impregnation
- GRP appeared white only *after* curing





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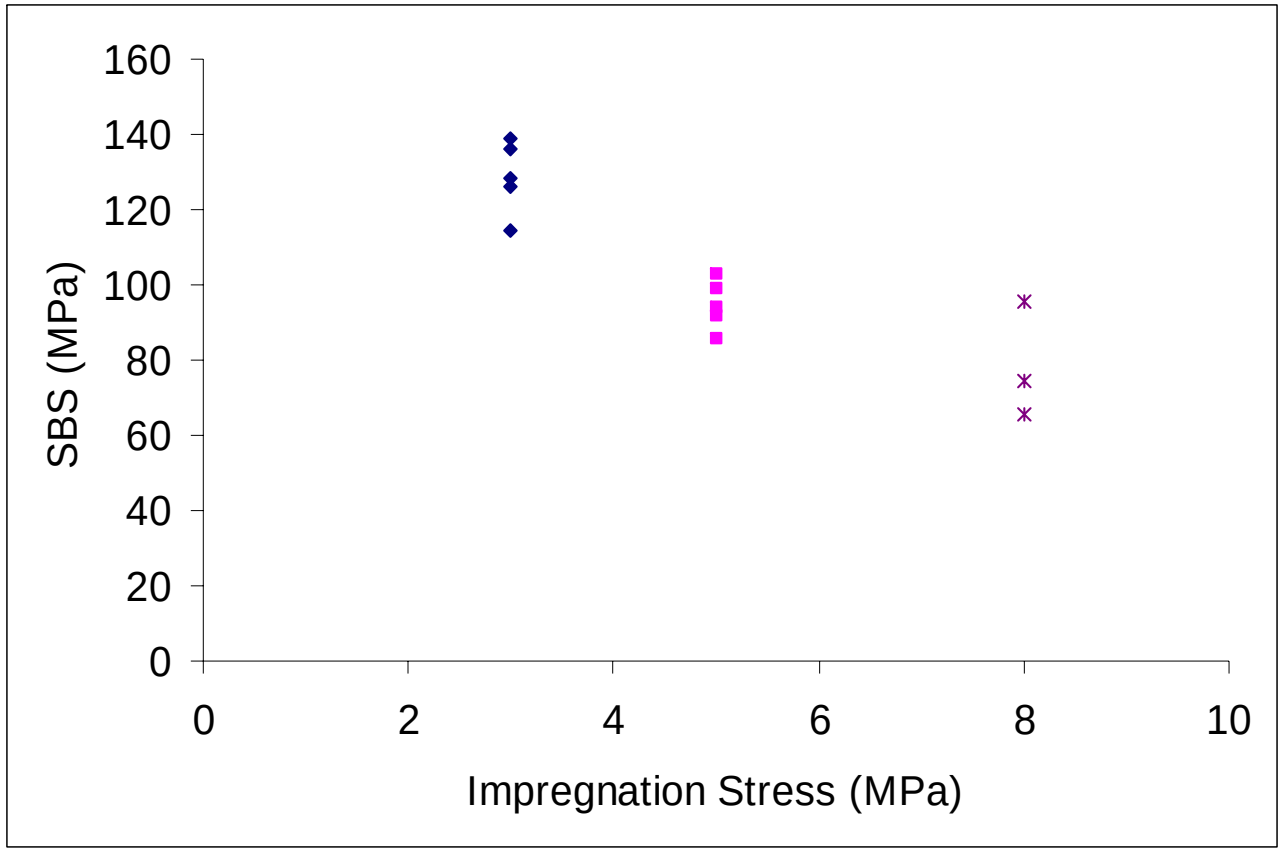
Effect of applied stress on Short-Beam-Shear Strength



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Opacity is a good guide to laminate strength

SBS (MPa)

116

110

102

72

47

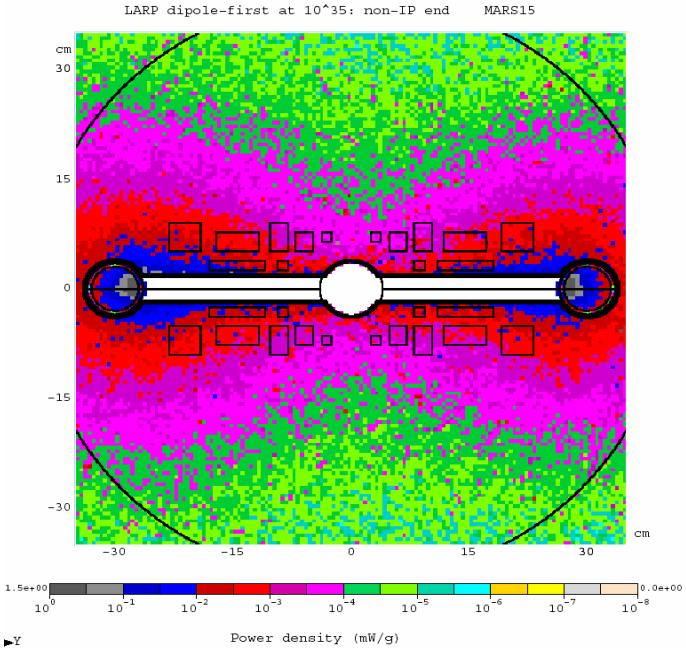
34

transparent

opaque

Radiation issues

- LHC IR upgrade - very high heat and radiation loads (up to 500MGy) - makes cos-theta design impractical for an organic insulation
- USA (LARP) working on an "open-midplane" design, reduces heat loads from 50mW/g to <1mW/g.
- Heat absorbed in tungsten rods at 77K
- S-LHC (energy upgrade) dipoles - far lower radiation loads, conventional cos-theta design more realistic *(1000+ magnets)*



Mohkov, CARE meeting March 2005

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Radiation testing

- Need an irradiation test facility with *realistic spectrum* (50% hadrons) at *low temperatures*
- Why realistic spectrum?
  - High energy hadrons are more damaging to organic insulation materials than gamma
- Why low temperatures?
  - At low temperatures evolved species (H_2, CH_3 etc) are frozen into the organic matrix.
  - On warming the trapped gases can be damaging

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Thin S-glass and quartz tapes

- Total turn-to-turn insulation thickness 0.4mm max, so 0.1mm tape required. Not standard products
- JPS Composites Inc. have woven specially thin S-glass and quartz for NED, down to 0.06mm
- Meets NED insulation thickness specification

ATLAS conductor + 2 * 0.1mm thick S-glass tape

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Conclusions

- Polyimide sizing offers improved materials properties for Nb3Sn insulation
- High stresses during resin impregnation and cure reduce shear strength
- Thanks to:
  - *Hydrosize Technologies Inc.* – supplier of polyimide sizing
  - *JPS Composites* – weaver and supplier of S-glass and quartz with polyimide sizing
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